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UGV Simulations and Modeling in a SIL Environment

Rich Goetz and Grant Gerhart
US Army Tank-automotive RDE Center (TARDEC)
Warren, MI 48397-5000
goetzr@tacom.army.mil
gerhartg@tacom.army.mil

ABSTRACT

There are a variety of efforts attempting to integrate unmanned vehicle systems into the Army array of tools and weaponry. Military planners for Force XXI and Army After Next are busy assessing the viability and potential usability of unmanned vehicles of all types – land, sea, and air -- in the near, mid and far term. But exactly how can we create a facility that can offer baseline performance metrics and assess a wide variety of UGV platforms, configurations and weight classes? This paper will present efforts to develop a Systems Integration Laboratory (SIL) environment which will focus on testing and validation of a variety of candidate small and mid-sized unmanned ground vehicles emerging from the various Department of Defense (DOD) UGV programs. A description of the SIL concept for UGVs will be provided as well as how it is being applied in the Intelligent Mobility Robotics program at the US Army Tank-automotive and Armaments Research, Development and Engineering Center (TARDEC). The test areas will be described as well, including the Supervised Navigation Test area, the Modeling and Simulation room and the Hot Bench & Test Integration Room. The paper will also summarize the expected activities planned to be conducted in the lab, the range of unmanned prototype vehicles, which may be tested in this facility, and various modeling and simulation concepts planned for the future. Finally, a description of what makes this research facility unique to DoD will be offered.

INTRODUCTION

The notion of using robotic technology on military ground vehicles has been seriously considered for only during the past 20 years or so. The focus of implementing these unmanned vehicle systems – whether they are on the ground (UGV), in the air (UAV), or underwater (UUV) – is to act as either a force multiplier, or to keep soldiers from performing dangerous missions. These kinds of uses are becoming increasingly important given the increasing social and political demands for a minimum amount of casualties in any military operation. The larger question is how to implement these technologies efficiently and have the military leadership gain confidence in the ability for using these unmanned vehicles to act as an additional vehicle or weapon for the individual soldier. A major transformation of military tactics and structure will commence once unmanned vehicles become commonplace and are considered a part of the typical military unit.

PRESENT AND FUTURE ROBOTIC CONCEPTS

Unmanned vehicle systems are primarily being pursued in the military services because of their perceived ability to assist the solider in the field in performing assigned tasks in some manner. DOD is developing of an array of unmanned vehicle concepts for three primary reasons. The first reason is to minimize and reduce injury risk to all soldiers. Unmanned systems will increase individual soldier and system survivability by reducing their exposure to battlefield hazards. Mission mine clearing tasks and information scouts.

The second reason for development is to use these unmanned systems as a force multiplier. Unmanned systems will increase force capabilities in several categories, including lethality, survivability, situational awareness, force protection and sustainability.

Lastly, the biggest potential long-term payoff for development and implementation of UGV systems is the prospect of having a vehicle or weapon that requires only minimal direct human involvement after being assigned a task or mission. This, in fact, is the definition of autonomous mobility – being able to internally be given a task and complete it without human intervention. Unfortunately, this type of system is still to be fully realized [1]. Unmanned systems will likely be very specialized and situational dependent. However, they will have a variation of abilities and will likely be employed across the range of military operations.

Current DOD efforts

Most advanced development projects related to unmanned ground vehicle robotics have been consolidated under the

Joint Robotics Program (JRP) directed by the Office of the Secretary of Defense (OSD). JRP is responsible for launching the development of first generation UGVs and related technologies that are deemed critical to follow-on systems. Their goal is to develop and field a family of unmanned ground vehicle systems for a range of military applications in accordance with user requirements. These vehicles range in size from microbots – which can fit in the palm of a person's hand – to teleoperated tanks, such as the Turretless M-60 Panther, which is currently being used to detonate Anti-Personnel mines in Bosnia.

The long-term goal is to mature critical technologies to move robotic applications forward from teleoperation— where a human directly controls UGV functions — to semi-autonomous and autonomous functioning. Semi-autonomous performance of a UGV is a vehicle that functions with the operator only in a supervisory role and thus able to control multiple UGVs concurrently. Autonomous performance of a UGV would be realized when a set of instructions would be carried out without human interaction during the task.

TARDEC Robotics programs

Demo III is the cornerstone of the Joint Robotics Program UGV Technology Enhancement and Exploitation (UGVTEE), tech-base, program which is managed by the U.S. Army Research Laboratory (ARL) and coordinated through TARDEC. The goal of the Demo III Program is to develop technology required to demonstrate a small, survivable unmanned ground vehicle capable of autonomous operation over rugged terrain as part of a mixed military force containing both manned and unmanned vehicles. The vehicle (see Fig. 1) will weigh approximately 2,500 lbs., and be able to maneuver cross-country at speeds of up to 20 mph during daylight, 10 mph during darkness, and up to 40 mph on roads during daylight. This will allow it to successfully operate with a mixed maneuver force during tactical operations.

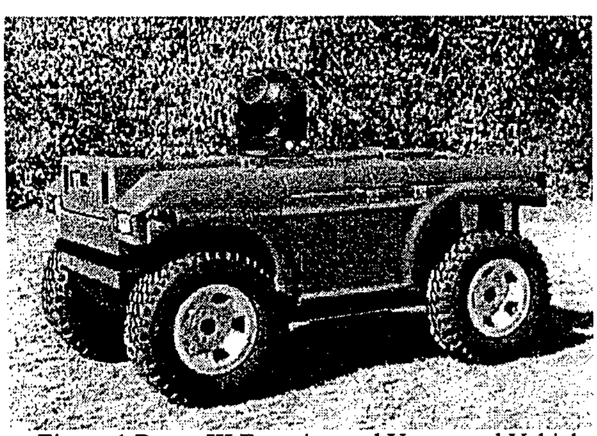

Figure 1 Demo III Experimental Unmanned Vehicle

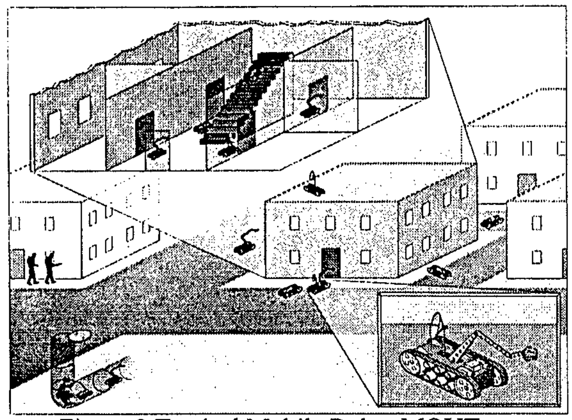

Figure 2 Tactical Mobile Robot MOUT concept: 10 robots to clear 20 rooms in 60 minutes

Tactical Mobile Robotics (TMR) is a DARPA funded program to develop advanced mobile robotic technologies for man portable platforms – targeted at between 10 and 40 pounds --- and integrate them into systems which will be demonstrated in tactical operations. The primary technologies to be developed are robust obstacle negotiation, fault tolerant autonomy, multi-platform perception, and denied area mapping. The program objective is to design, develop, and demonstrate the use of small robot teams in realistic, tactically significant scenarios. Emphasis is placed on man portable platforms working in complex, obstacle intensive environments and denied areas. The primary mission profiles are reconnaissance oriented, with collateral value realized through delivery of specialized mission payloads such as communication relay and mobile obscurant (smoke) projection. A variety of more sensitive mission payloads are also anticipated.

Intelligent Mobility Robotics program

The TARDEC Intelligent Mobility (IM) robotics program is designed to complement and extend survivability and mobility requirements of several DOD robotics programs such as Demo III and Tactical Mobile Robots. Primary program objectives are to develop enhanced mobility and survivability technologies and subsystems for UGV programs in locomotion, machine perception and supervised navigation. IM will also augment present navigational system limitations by developing "smart" drive system technologies via feedback control at its key elements. The work during the first year of the program will focus on vehicles between 100 and 1,500 pound in size. Utah State University has developed two vehicles in the first year of the program. A sub-scale 95-pound omni-directional vehicle (ODV) called T1 (see Fig. 3) was delivered in November 1998, while a mid-scale ODV approximately 1,250 pounds called T2 (see Fig. 4) was demonstrated to the Government in June 1999.

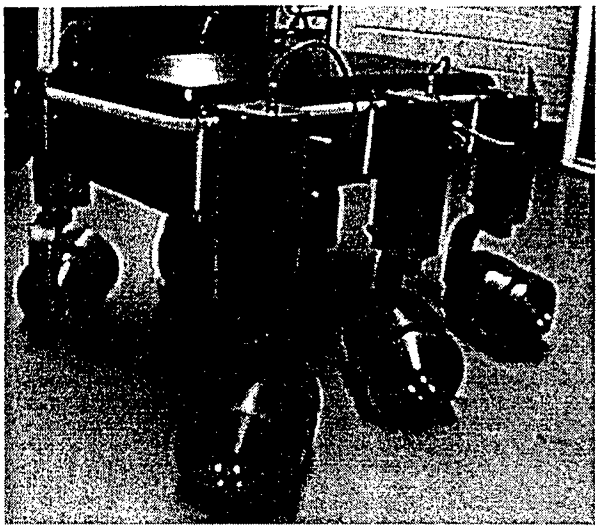

Figure 3 Intelligent Mobility T1 concept vehicle developed by Utah State University

The essential vehicle elements of both concept vehicles are the running gear configuration, command and control, and path planning. These systems interface with the external world via the soldier interface and digital battlefield communications. The vehicle world model will use a tactical decision aid that exploits situational awareness to determine vehicle operation on the battlefield. Critical elements of the situational awareness algorithms will the synergism between intrinsic mobility and signature management. The tradeoff between moving undetected while avoiding and negotiating obstacles will give tactical flexibility for the UGV to accomplish its mission.

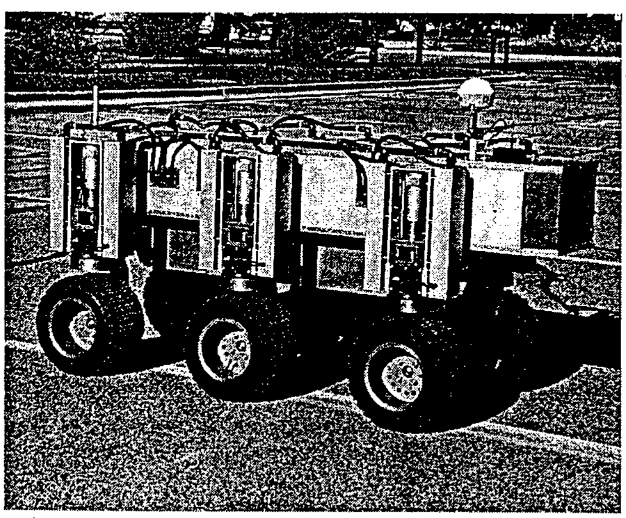

Figure 4 Intelligent Mobility T2 concept vehicle developed by Utah State University

The sub-scale T1 contains an in-hub electric drive system where each wheel has two degrees of freedom (2-DOF). The wheel hub assembly includes the electric motor, processor board, batteries and an optical slip ring, which connects the drive electronics to the on-board vehicle controller. The aggregation of six independent wheels using an intelligent controller gives the T1 vehicle omni-directional steering (ODS) capability. This unique concept allows the UGV to perform more complex maneuvers such as right angle turns that are currently not possible with an Ackerman steering drive system. Future UGV systems will deploy intelligent wheels with z-axis or 3-DOF allowing the vehicle chassis a 6-DOF motion capability.

The mid-scale T2 also demonstrates the off-road mobility and survivability advantages of cooperative multi-vehicle command and control. A number of iterative changes have been incorporated into the T2 design including moving the batteries and power conditioning equipment out of the wheels and into the vehicle chassis. The T2 is an electric vehicle with no internal combustion engine providing power as in hybrid electric systems. However, the original ODV concept remains intact.

SIL DEVELOPMENT

The concept of a systems integration lab (SIL) has been traditionally used in evaluating complex systems such as vehicle electronics and hydraulics. A SIL is usually set up to allow a "coupling" of prototype system elements. This can be combining two separate hardware technologies, or by joining a piece of hardware with software. For experimentation purposes, the remaining system elements are simulated via software. Traditional SIL applications also include the ability to exercise the system in a mission realistic manner. Prototype hardware is individually brought online until the entire system is functioning together. It is also important that the test vehicle be in proximity to the SIL to allow consistent evaluation of system characteristics during the transition of hardware and software from the SIL into the vehicle.

TARDEC has also designated approximately 4,300 sq.ft. for construction of a SIL to extend the capabilities of the Intelligent Mobility robotics program. This facility will include three major areas for laboratory testing, including a supervised test navigation area, a hot bench and test integration lab, and a modeling and simulation lab.

PROPOSED LAB ACTIVITIES

The SIL was created to perform developmental testing and evaluation of a variety of small-scale UGV systems,

focusing on mobility and survivability technologies. The primary areas for performing these tasks include a supervised navigation test area, a hot bench & test integration room, and a modeling and simulation room. Besides the Intelligent Mobility program, it is foreseen that it will extend the capabilities of a variety of parallel DOD sponsored UGV research efforts, including the aforementioned Demo III and TMR programs.

The laboratory environment will provide ample opportunity to work with these types of vehicles and related technologies in a controlled environment. The Intelligent Mobility program is also investigating opportunities to partner with a military user and/or MOUT (Military Operations in Urban Terrain) facility in order to extend the ability to acquire field data via user interactions with UGVs. Design of the lab has been completed. It is expected that the facility will be operational in FY2001.

Supervised Navigation Test Area

An obstacle course will be constructed in the supervised navigation test area. The course will include several positive and negative obstacles for small-scale unmanned vehicles. Such items as an indoor rock bed, stairs, and a variety of soil types would be incorporated. Several vehicles can then be ran through the course and graded for ability and speed of movement throughout. Testing of navigation and locomotion over these standardized mobility obstacles will be available in this facility. Obstacle detection and avoidance technologies can also be validated here as well.

An endurance test will also be developed. This will gather data on the total distance a UGV travels before losing its ability to move, operating time, and the resulting average speed. Studies may be performed to determine what the nominal operation time might be for any given mission.

Traditional test procedures from legacy (manned) vehicle systems will be used as the starting baseline. Many can be implemented with either little or some adaptation for unmanned ground vehicle systems. From this beginning, test procedures specific to the testing and validation of unmanned vehicle systems may be developed. The goal is to provide data for various types of UGV model validation.

The following are examples of some candidate parameters to be considered for test and validation issues in the test area:

<u>Physical dimensions:</u> Validation and assessment of platform characteristics to evaluate, including but not limited to: length, width, height, ground clearance, weight, and ground pressure.

<u>Tractive Effort:</u> The ability of the vehicle to move its own weight. That is, does the vehicle have the traction and horsepower to transfer power from its powerpack to the ground for mobility purposes? This can be evaluated for both flat terrain and transverse grades/slopes.

<u>Forward/Reverse Speed</u>: The movement of the vehicle and its maximum/minimum speed in forward and reverse. Vehicle acceleration and braking may also be evaluated as well.

<u>Steering:</u> The minimum turning radius of the vehicle and type of steering employed.

<u>Trench crossing:</u> A standardized trench can be developed and built based on the parameters of the vehicles to be tested.

<u>Vertical step:</u> It is foreseen that UGVs involved a MOUT scenario will literally need to climb up and down steps between floors. A standardized step will need to be defined and developed. However, specific vehicle requirements will demand adaptation from that standard.

<u>Fording:</u> Legacy vehicles are required to move through shallow bodies of water. It is not yet known what requirements UGVs will have, but should be considered in the SIL development.

<u>Power management</u>. The location and use of power within the vehicle's operational budget is essential to the completion of the planned missions. The SIL may provide an opportunity to evaluate power generation, power storage, and power distribution.

<u>Actuators/Resolvers</u>: Mechanical devices to move and devices to sense movement of those devices need to be tested in the SIL, particularly electrical and mechanical interfaces.

<u>Suspension:</u> Vibration effects of the suspension will degrade sensor performance. Therefore, it will be necessary to evaluate its performance.

<u>Route following:</u> A variety of sensor inputs such as navigation, stereo vision, map database should be evaluated for performance.

<u>Communications</u>: System internal and external communications are essential to UGV functions: teleoperation and data bus for example. The SIL must be given the facility equipment and structure to allow for the

safe operation of external communications equipment during UGV performance evaluation.

These are only a cursory list developed of the types of parameters to test and evaluate within the SIL [5]. The navigation test area will also be used to evaluate sensor suites for their perception performance on nominal UGVs. In this application, the sensors will be judged on their abilities to assist the vehicles in obstacle avoidance and obstacle detection.

Hot Bench Test & Integration Room

The Hot Bench and Test Integration room is envisioned as a place where researchers investigate individual components and subsystems of small-scale UGVs. An individual piece of vehicle hardware may be highlighted within a virtual UGV system, for example. Once isolated, it can be tested for performance off of the vehicle. Furthermore, new and unique technologies may be integrated in a similar fashion and its performance compared before it may be added to the UGV itself. This offers the ability to evaluate a variety of unique prototype technologies for increasing the mobility and survivability of small-scale UGVs.

The area is also being considered to be a tool for both government and contractors to join together and test the compatabilities of variously independent subsystems. Since many contractors are pursuing the same goal, it is important for the Government to provide a facility to merge hardware and software concepts.

Modeling and Simulation Room

There are three basic areas of work envisioned for this aspect of the SIL. First, is the development of new engineering models. An example of this might be developing UGV-based terrain models for both small-scale and mid-scale prototypes and applying the results to assist the user community in determining how to strategically incorporate UGVs into their missions.

Intelligent Mobility robotics personnel have already begun to review several mobility models such as NRMM to provide additional data. Most of the existing data has been developed for legacy vehicles. However, validation tasks have not been performed for vehicles roughly 1,000 pounds or less. They also have not considered anything but man-in-the-loop scenarios. New models are anticipated to develop as a result from this effort.

Secondly, is the chance to validate control algorithms that will come along from developers. We anticipate using the Modeling and Simulation area in conjunction with the Supervised Navigation Test area to perform these tasks. Lastly is the potential for wargaming simulations. Since UGVs are a new vehicle class, in a sense, little is known in the user community to how to apply these best in accomplishing a variety of mission tasks.

To assist the user, the Intelligent Mobility robotics program is actively seeking collaboration with the US Army Infantry School at Ft. Benning, GA. Ft. Benning offers the McKenna MOUT site for conducting infantry exercises. McKenna has seven buildings wired for video, sound and continual monitoring. Furthermore, it has an adjoining computer lab facility in place to track movement of soldier activity for experiment and review.

Discussion is underway to have UGVs which pass muster through the Supervised Navigation test area operate in the MOUT facility and transmit the resultant data back to Intelligent Mobility for analysis. A potential mission would be to use the field data to assess how and if infantry goals for incorporation of UGVs are reachable.

POTENTIAL COLLABORATIONS

There are several potential collaborations for the Intelligent Mobility SIL. This includes the previously mentioned the US Army Infantry School at Ft. Benning, GA and assisting the user in updating the ORD for Man Portable Robotics Systems, which are classified in the 10-40 pound platform range.

TMR offers the best opportunity for gathering a handful of different platforms in the near future. TARDEC has been named as the TMR robot repository, and as such, needs to provide storage and maintenance of the back-packable UGVs. The Intelligent Mobility SIL offers a place not only for storage, but ample opportunity to perform additional test and validation on the systems.

As part of the Demo III Concerted Technology Thrust, the SIL may provide unique technologies such as the Utah State omni-directional steering or the Intelligent Wheel system. There may be opportunity to merge some systems within the Hot Bench and Test Integration room.

Other potential collaborations include dual-use applications sponsored by the National Automotive Center (NAC) for the 21st Century Truck; UGV/S JPO efforts, and the potential for miscellaneous contractor work and CRDAs.

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